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A comparative analysis of South African Life Sciences and Biology textbooks for inclusion of the nature of science

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This study reports on the analysis of South African Life Sciences and Biology textbooks for the inclusion of the nature of science using a conceptual framework developed by Chiappetta, Fillman and Sethna (1991). In particular, we investigated the differences between the representation of the nature of science in Biology textbooks that were written for a previous curriculum and the new Life Sciences textbooks that are in accord with the National Curriculum Statement. The analysis reflects that both Life Sciences and Biology textbooks still overwhelmingly represent the theme "Science as a body of knowledge" according to this framework. Despite significant curriculum reform that underlines a more balanced perspective of science encompassing the acquisition of knowledge through inquiry, the limited coverage given to the themes "The investigative nature of science", "Science as a way of thinking" and "The interaction of science, technology and society" does not reflect this reform.

Keywords: Biology textbooks; Life Sciences textbooks; nature of science; school science curriculum; science textbook analysis

Introduction

The value of textbooks in driving the teaching of science has been well-documented. The importance given to the textbook is encapsulated by Abd-El-Khalick, Waters and Le (2008:836), who remark that in the large majority of classrooms, textbooks become "the classroom, and determine what is taught and learned about science in these classrooms". Textbooks help translate the intentions of the curriculum into classroom practice by reflecting the goals of science learning, such as understanding the nature of science (NOS) and science content; developing inquiry skills; and understanding the interrelationship of science, technology, the environment and society (Albach & Kelly, 1998). The quality of textbooks, therefore, has a great impact on the quality of instruction (Lemmer, Edwards & Rapule, 2008). Furthermore, the availability of high quality textbooks is one of the critical factors in the successful implementation of curriculum reform (Swanepoel, 2010).

In South Africa, curriculum reform in school science has affirmed the prominence that ought to be given to the NOS in the teaching of school science subjects. Due to the value of the textbook in driving curriculum reform, this article reports on the analysis of South African Life Sciences and Biology textbooks for the inclusion of the NOS. In particular, we investigated the differences between the coverage given to the NOS in Biology textbooks that were written for the previous National Assembly Training and Education Department (NATED) 550 curriculum, and the new Life Sciences textbooks that are in accord with the *National Curriculum Statement* (NCS).

The construct "nature of science" has been advocated as an important educational outcome by various school science curricula worldwide. Lederman (2007:831), in fact, states that one would be hard pressed to find rhetoric arguing against its importance as a "prized educational outcome". Driver, Leach, Millar and Scott (1996) maintain that the NOS is a critical component of scientific literacy. While support for the NOS has been overwhelming in the science education community, there is some dissonance in the literature as to what it means (Laugksch, 2000). However, a review of the literature by Schwartz and Lederman (2002) shows that there is an acceptable level of agreement on what it entails. Lederman (2007:833) identifies the basic tenets of the nature of scientific knowledge as follows:

> It is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), and subjective (involves personal background, biases and/or is theory laden); necessarily involves human inferences, imagination, and creativity (involves the invention of explanations; and is socially and culturally embedded). Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between, scientific theories and laws.

In South Africa, the publication of the NCS for Life Sciences, a subject taught to students in the Further Education and Training phase (Grades 10–12) (Department of Education, 2003), marked a significant departure from the previous apartheid-era curriculum (NATED 550). NATED 550 had a narrow conception of scientific literacy that depicted science as a static body of knowledge. The subject Life Sciences was previously known as Biology, and the Biology syllabus required students to "learn chunks of biological facts that they had to regurgitate in tests and examinations" (Le Grange, 2008:94). Furthermore, Le Grange (2008) maintains that the school subject, Biology focused mainly on the study of plant and animal life, with the artificial separation of fact and value. This focus led to the privileging of factual knowledge over values under the influence of positivism.

Mnguni (2013:2) cites Cotti and Schiro (2004) in describing this emphasis as "the scholar academic ideology that deals with disciplining students by transmitting discipline specific knowledge".

The view of science depicted by the previous NATED 550 curriculum was, therefore, incompatible with the tenets of the NOS as underlined by Lederman (2007). The NCS for Life Sciences states that "through the study of the Life Sciences, learners can develop an understanding of the nature of science" (Department of Education, 2003:9). This curriculum goal is in line with the tenets of the NOS encapsulated by Lederman (2007).

For an emerging economy such as South Africa to grow, higher-order intellectual skills should be strongly emphasised. Whereas skills in set tasks were valued in the past, today each worker is expected to think critically, solve abstract problems and generate new ideas for improvement (Castells, 2005). To enhance the transfer of these learnt skills to other environments, learners should be exposed to multiple contextual situations in which they engage with socio-scientific challenges such as Human Immunodeficiency Virus (HIV)/AIDS (Acquired immune deficiency syndrome), and environmental management (Mnguni, 2013). Lederman (2007) maintains that creativity and imagination play an important role in science, and regards this as a tenet of the NOS. This suggests that a science curriculum that places a high imperative on the NOS will inculcate in learners some of the higher-order skills required by the workforce of an emerging economy.

Despite the strong NCS focus on the NOS, teachers received little support when it comes to how to develop materials that would facilitate a legitimate view of the NOS. This lack of guidance on how to design curriculum materials opened the door for a plethora of textbooks entering the market. Owing to their limited capacity to design curriculum material, teachers relied heavily on the textbook as a vehicle for implementing the intended curriculum (Malcolm & Alant, 2004). This scenario accompanying curriculum reform in South Africa was not unexpected, because in order "to achieve large-scale reform, you cannot depend on people's capacity to bring about substantial change in the short run, so you need to propel the process with high quality teaching and training materials" (Fullan, 2001:79). It therefore becomes pivotal for teachers and curriculum planners to be aware of the quality of textbooks.

Despite the curriculum emphasis on learners acquiring an understanding of the NOS, and the key role of the textbook in supporting teachers to address this emphasis, analyses in other countries of science textbooks show that certain aspects of the NOS are not sufficiently addressed (Abd-El-Khalick et al., 2008; Chiappetta & Fillman, 2007; Lumpe & Beck, 1996; McComas, 2003). Abd-El-Khalick et al. (2008) in their analysis of high school Chemistry books used over four decades in the United States (US), rated them poorly in their representations of the NOS. More specifically, McComas (2003) found, in his analysis of US Biology textbooks, that the distinction between laws and theories (aspects of NOS) was not evident. He recommended that authors take more care to provide accurate and complete definitions coupled with useful examples. In South Africa, limited analysis of science textbooks has been undertaken, specifically analysis of the textbooks that have accompanied recent curriculum reform for their inclusion of the NOS.

The role of the textbook as a resource in advancing the tenets of the NOS is especially critical in the South African context. Studies on teacher understanding of the NOS in this country have revealed that teachers have an inadequate understanding of the NOS. A study conducted by Dekkers and Mnisi (2003) in the Limpopo Province found that the majority of teachers surveyed believed common myths about the NOS, as identified by McComas (1998). For example, teachers believed that "hypotheses become theories that in turn become laws" and that "scientific laws and other such ideas are absolute." A study by Linneman, Lynch, Kurup and Bantwini (2003) with teachers in the Eastern Cape arrived at a similar finding. Given this scenario, a shift in the practice of teachers can be supported through the development of textbooks that reflect a more balanced coverage of the NOS.

It is against this background that we investigated the way in which South African Life Sciences and Biology textbooks depict the NOS. Furthermore, we wanted to know how the coverage of the NOS in the current Life Sciences textbooks differed from that in the Biology textbooks that were used in the previous NATED 550 curriculum. Accordingly, the following research questions were formulated:

1) To what extent do South African Life Sciences and Biology textbooks depict the nature of science?
2) How do Life Sciences and Biology textbooks compare in the extent to which they cover the nature of science?

Conceptual Framework for Textbook Analysis

A critical aspect of any analysis of information is the conceptual framework used to guide the inquiry. We adopted a conceptual framework developed by Chiappetta et al. (1991) for analysing themes in the NOS. This framework has been employed extensively by researchers in their analysis of textbooks (Abd-El-Khalick, 2002; Chiappetta & Fillman, 2007; Chiappetta et al., 1991). This framework addresses the four themes described below.

1) *Science as a body of knowledge:* This theme reflects science as a body of knowledge such as the

facts, concepts, principles, laws, theories and models.

2) *The investigative nature of science:* This theme reflects the active aspect of inquiry and learning, which involves the student in the methods and processes of science such as observing, measuring, classifying, inferring, recording data and making calculations.

3) *Science as a way of thinking:* This theme represents thinking, reasoning and reflection, where the student is told how the specific enterprise operates.

4) *Interaction of science, technology and society:* This theme pertains to the application of science and how technology helps or hinders humankind.

Each of the above themes in the NOS is elaborated on in greater detail through categories; this formed the basis for an analytical framework. The framework is presented in Table 1.

Table 1 Analytical framework for the NOS

NOS Theme		Descriptor: NOS Categories	
1.	Science as a body of knowledge	a)	Knowledge presented as facts, concepts, laws, and principles
		b)	Hypotheses, theories, and models
		c)	Factual recall of information
2.	The investigative nature of science	a)	Learns through the use of materials
		b)	Learns through the use of tables and charts
		c)	Makes calculations
		d)	Reasons out an answer
		e)	Participates in thought experiments
		f)	Gets information from the internet
		g)	Uses scientific observation and inference
		h)	Analyses and interprets data
3.	Science as a way of thinking	a)	Description of how a scientist discovered or experimented
		b)	Historical development of an idea
		c)	Empirical basis of science
		d)	Use of assumptions
		e)	Inductive or deductive reasoning
		f)	Cause and effect relationship
		g)	Evidence and/or proof
		h)	Presentation of scientific method(s) or problem solving
		i)	Scepticism and criticism
		j)	Human imagination and creativity
		k)	Characteristics of scientists (subjectivity and bias)
		l)	Various ways of understanding the natural world
4.	Interaction of science, technology and society	a)	Usefulness of science and technology
		b)	Negative effects of science and technology
		c)	Discussion of social issues related to science and technology
		d)	Careers in science and technology
		e)	Contribution of diversity
		f)	Societal or cultural influences
		g)	Public or peer collaboration
		h)	Limitations of science
		i)	Ethics in science

Source: Adapted from Chiappetta & Fillman (2007)

Methodology

A content analysis of three Grade Ten Life Sciences textbooks and three Biology textbooks was undertaken. Krippendorff (2004:18) defines this approach as "a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use". Books that were extensively used in classrooms throughout South Africa were targeted for analysis. The selection of these books was based on information about schoolbook orders provided by the Department of Basic Education. The three books chosen for Life Sciences had the highest number of orders, and they collectively constituted close to 70% of all book orders for Grade Ten. Similarly, the Biology books chosen were the three most popular in the NATED 550 curriculum.

We analysed the textbooks by applying the validated framework of Chiappetta et al. (1991). We first calculated 10% of pages for each textbook, as recommended by Chiappetta and Fillman (2007). We then applied a sliding scale, based on the proportion of pages allocated per content area, to calculate the number of pages to be analysed for each content area (Chiappetta & Fillman, 2007). The pages were then selected randomly by number generation from each content area. The four core content areas examined were: tissues, cells and molecular studies; structures and control processes; environmental studies; and diversity, change and continuity. The composition of each content area is shown in Table 2.

Table 2 Core content areas in textbooks

Core content area	Topics
Tissues, cells and molecular studies	Cell structure
	Cell division and mitosis
	Tissues
	Related diseases, e.g. cancer
Structures and control processes	Energy release
	Food production
	Human nutrition and related diseases and allergies
	Gaseous exchange and related diseases and allergies
Environmental studies	Biosphere, biomes and ecosystems
	Living and non-living resources
Diversity, change and continuity	Biodiversity of plants and animals and conservation
	Significance and value of biodiversity to ecosystem function and human survival
	Threats to biodiversity
	Parasitism and diseases, e.g. bilharzia

In the analysis we first highlighted the units of analysis. The units of analysis included complete paragraphs, activities, worked examples, figures with captions, tables with captions, charts with captions, and marginal comments. The units were coded independently according to the NOS categories set out in Table 1. This entailed studying a unit, and identifying the theme and category to which the unit could best be related. A deductive process was therefore followed in coding the units from the textbooks according to the Chiappetta et al. (1991) framework. Examples of units that corresponded to the themes and categories are presented in the results section. After the coders completed assigning each unit of analysis to a category in one of the four themes of the NOS, the reliability in the coding of the units was determined by the use of Cohen's *kappa* statistic. Cohen's *kappa* is calculated as follows: $k = (po - pc) / (1 - pc)$, where po is the proportion of ratings in which the two judges agree, and pc is the proportion of ratings for which agreement is expected by chance. Ethical clearance for this research was granted by the University of Johannesburg at which the first author is employed.

Results

The following pseudonyms are used for the three Life Sciences textbooks that were analysed: *Approaching Life Sciences*, *The Basics of Life Sciences*, and *Curiosity in Life Sciences;* and for the Biology textbooks, *Diverse Biology: An Exploration of Biology* and *Classroom Biology.* In total, 724 textbook units were coded to a particular category presented in Table 1. Between the coders there was agreement in coding 556 of these units, and this meant there was a 77% agreement in this process. The calculated kappa value was 0.7. According to Landis and Koch (1977), kappa values from 0.61 to 0.80 indicate a substantial level of agreement in coding. Coding differences were resolved through discussion. Consensus was eventually reached.

Table 3 shows the results on the coding of units for each of the six analysed textbooks. For example, in the book *Approaching Life Sciences,* 54% of units were considered to be related to the NOS theme "Science as a body of knowledge". The calculation of percentage coverage of the four themes was regarded as a valid means of comparison, as it addressed the implications of textbooks having different physical features such as page orientation, page size, and font type and size.

Figure 1 shows a visual comparison of the Life Sciences and Biology textbooks for the representation of the NOS themes.

We now discuss these results in terms of the four themes of the NOS.

Theme I: Science as a Body of Knowledge

The results show that the Life Sciences textbooks strongly manifest the theme "Science as a body of Knowledge", with 54% of the units of measurement devoted to this theme. The coverage in all three Biology textbooks is even more heavily dominated by this theme, with 84% of all units being coded to this theme. A deeper analysis showed that for the Life Sciences textbooks, 194 of the 227 units of analysis that were classified according to this theme corresponded to the category "Knowledge presented as facts, concepts, laws and principles". A similar observation was made from the coding of the Biology textbooks, with 92% of all units coded to this theme being categorised as "Knowledge presented as facts, concepts, laws and principles". The following two units extracted from *Approaching Life Sciences* and *Classroom Biology* exemplify the coverage in this category:

> Living organisms are found in oceans, lakes and rivers (hydrosphere), as well as in the air or atmosphere. There is life on the surface of the Earth as well as in the soil, under the surface of the Earth (lithosphere). All these parts of the Earth where organisms live are part of the Biosphere. *(Approaching Life Sciences)*
>
> These organelles (ribosomes) are extremely small granules scattered in the cytoplasm of all cells. They occur singly or on the external surface of the endoplasmic reticulum or in groups in the cytoplasm where they are known as polyribosomes.

> They contain ribonucleic acid (RNA) hence their name, and enzymes connected with protein synthesis. Ribosomes are the chief manufacturers of all cell proteins. *(Classroom Biology)*

The above unit from *Approaching Life Sciences* describes the biosphere of Earth. This unit corresponds to the category "Knowledge presented as facts, concepts, laws and principles", because the paragraph presents facts on the habitat of living organisms. A similar focus is noted in the unit from *Classroom Biology,* where facts are presented on the ribosome.

In promoting the theme "Science as a body of knowledge", there appears to be a belief that scientific knowledge can be acquired and understood by learners when presented through clear and coherent explanations (Chiappetta & Fillman, 2007). The visual representation of concepts is often used to enhance this knowledge acquisition. This was evident in diagrams from *Curiosity in Life Sciences* on the formation of proteins from amino acids, which showed the linking together of amino acids in long chains to form proteins.

It would appear that a strong goal in the teaching of science from the perspective of both Life Sciences and Biology textbook authors, is for learners to acquire scientific knowledge. With regard to curriculum reform, it is clear from the extensive coverage given to this theme that a strong goal in the learning of science remains the acquisition of knowledge. This focus coheres well with the curriculum imperative in the more recent Curriculum and Assessment Performance Statement (CAPS) for Life Sciences expressed through Specific Aim 1, which specifies the construction of ideas and concepts.

Table 3 The percentage of coverage of the four themes of the NOS in three Life Sciences and three Biology textbooks

NOS Themes	*Approaching Life Sciences*	*The basics of Life Sciences*	*Curiosity in Life Sciences*	*Diverse Biology*	*An exploration of Biology*	*Classroom Biology*
Science as a body of knowledge	54	63	44	76	94	81
The investigative nature of science	27	22	33	12	6	19
Science as a way of thinking	8	5	8	0	0	0
Interaction of science, technology and society	11	10	15	12	0	0

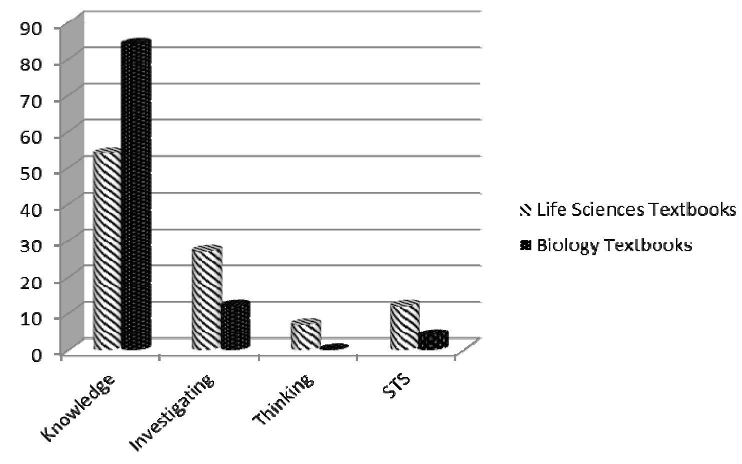

Figure 1 A comparison of the Life Sciences and Biology textbooks used in this study

Theme II: The Investigative Nature of Science

The investigative approach to the teaching and learning of science is portrayed moderately by all three Life Sciences textbooks as evidenced by the 28% coding of units to the theme "The investigative nature of science". This coverage is even more limited in the three Biology textbooks, where only 12% of units were devoted to this theme. In terms of the CAPS, it is clear that this theme aligns closely with Specific Aim 2 on planning and carrying out of scientific investigations. A comparison of the textbooks of the two subjects suggests that the increased percentage coverage of this theme in the Life Sciences textbooks reflects attempts by textbook authors to address the investigative approach to learning. However, the scope given to this theme in the Life Sciences textbooks suggests that this learning outcome is not being adequately addressed.

For the Life Sciences textbooks, the units coded to the theme "The investigative nature of science" were overwhelmingly situated in the category "Learns through the use of materials" (107 of 120 units). An activity in *The basics of Life Sciences* on the use of yeast to show alcoholic fermentation falls within this category. In this coded unit, learners are presented with a diagram of the apparatus and then instructed to set up the apparatus. They are then given a procedure for conducting the investigation. The intention of this activity is to engage the learners in a hands-on learning situation in the manipulation of objects. In this and other units coded to this category, emphasis is placed on the development of procedural skills in handling the apparatus and making observations. However, the textbooks do not facilitate the development of other process skills such as hypothesising, planning an investigation, making an inference, analysing data, and reflecting on findings. This would suggest that the textbooks support learners in having only limited autonomy in scientific investigations. In other units, where this theme is addressed, the focus is on learners conducting investigations, with little or no scope being given to the design of investigations.

The analysis suggests an emphasis on learners doing practical work in confirming a given concept, law or principle that had been previously learned, rather than learners being given the opportunity to investigate their own ideas.

Theme III: Science as a Way of Thinking

The theme "Science as a way of thinking" is poorly represented in all six textbooks. For the Life Sciences textbooks, an average of 7% of units was coded to this theme. This theme was not addressed in any of the three Biology textbooks. Both sets of textbook authors do not convey, to any great extent, how the scientific enterprise operates. In the Life Sciences textbooks, where text was devoted to this theme, the focus was given to the category "Describes how a scientist discovered or experimented". The following example of such a unit is taken from *Approaching Life Sciences:*

> In 1771, Joseph Priestly (1733-1804) placed a green plant into air in which a candle had burned out and found that ten days later another candle could be burned in the same air. He reported that he had 'accidently hit upon a method of restoring air that has been injured by the burning of candles'. He then tried the same experiment with a mouse and found that the mouse lived in the same air. *(Approaching Life Sciences)*

The objective of this unit is to show how Priestley experimented on the purification of air using green plants. There was little or no evidence of the other categories in this theme. For example, little material highlighted the empirical NOS, the inductive and deductive NOS, and the relationship between evidence and proof. A few units related to the empirical NOS. The following is an example of a unit from *Approaching Life Sciences* that addresses the empirical NOS:

> Measuring pH
> Collect a water sample. Add a few drops of universal indicator. Compare the colour of the water with the code on the indicator bottle. The pH for healthy, unpolluted water will be between 6.5 and 8.5. Interpret your results using the table on your right. *(Approaching Life Sciences)*

Theme IV: Interaction of Science, Society and Technology

The average percentage coverage of units for all three Life Sciences books given to this theme was only 12%. The average coverage of this theme in the Biology textbooks was four percent. Despite the curriculum imperative as specified in Learning Outcome Three of the NCS for learners to understand the interrelationship between science, society and technology, it would appear that the Life Sciences textbooks have not, in any significant measure, increased the coverage given to this theme.

All six textbooks represented this theme to approximately the same degree. The great majority of units coded for this theme were located in the category "Usefulness of science and technology". Units coded to this category exemplified the applications of science and technology in society. Examples of such units from *Curiosity in Life Sciences* and *An exploration of Biology* are:

> Biological washing powders contain enzymes that can act on protein-based stains. The enzyme found in these washing powders is a protease that breaks down proteins in the stain, producing smaller molecules that can then be removed by the detergent in the washing powder. *(Curiosity in Life Sciences)*
>
> Farmers can practice good farming methods to control soil erosion by contour ploughing and planting. They can also leave a strip of natural bush or grassland on each side of a stream or river and not planting crops right up to the river banks. *(An exploration of Biology)*

The first excerpt explains the role of enzymes in washing powders and indicates its potential use in society, while the second describes good farming practices that can guide farmers in overcoming soil erosion.

Discussion

The analysis of the textbooks for the four themes reflects that both Life Sciences and Biology textbooks still overwhelmingly represent the theme "Science as a body of knowledge". Significant curriculum reform underlines a more balanced perspective of science encompassing the acquisition of knowledge through inquiry, the development of scientific thinking and the interaction between science, society and technology. The coverage in the Life Sciences textbooks does not reflect this. A comparison of the Biology textbooks of the previous curriculum and the Life Sciences textbooks of the reformed curriculum revealed only minimal shifts towards addressing the other themes in the NOS. This finding correlates well with studies in other countries on the analysis of science textbooks against the background of curriculum reform. A study by Lumpe and Beck (1996) examined seven Biology textbooks using the same framework by Chiappetta et al. (1991). They concluded that the textbooks did not reflect the intended science education reform. Similarly, a study by Abd-El-Khalick (2002) reported that four popular science textbooks used in the US were devoid of important elements that define the NOS.

In view of the critical role played by the textbook in driving the teaching of science, the findings of this study raise concerns about the extent to which curriculum imperatives are being translated into practice. The findings suggest that the use of the textbook as a resource is undermining the advancement of the tenets of the NOS. A direct implication of this finding is that learners are not given the opportunity to acquire skills associated with activities that underlie the NOS. As pointed out earlier, growth in an emerging economy such as South Africa depends to a large extent on higher order skills in science and technology such as critical thinking, creativity, and problem solving. These skills could be acquired through learning that is aligned with the tenets of the NOS.

The reality of the classroom is that teachers give priority to assessments. The textbook industry in South Africa is huge, and publishers mandate writers to produce books that support teachers in preparing learners for these assessments to ensure a sizeable share of the market. Despite curriculum reform that strongly focuses on learner understanding of NOS, there is a strong focus on high-stakes summative assessment in the form of tests and examinations in South Africa's education system. This is significant as Blanchard, Southerland, Osborne, Sampson, Annetta and Granger (2010) allude to studies (e.g. Saka, Southerland & Brooks, 2009; Shaver, Cuevas, Lee & Avalos, 2007) that indicate the high-stakes influence of standardised summative assessments on the classroom practice of science teachers. These assessments are heavily weighted towards testing science content knowledge, and hence the textbook coverage on the NOS is strongly skewed towards the theme "Science as a body of knowledge". Substantial change in the emphasis of textbook coverage can be achieved if assessments place more attention on the themes "Science as a way of investigating", "Science as a way of thinking" and "Science, technology and society".

Furthermore, Abd-El-Khalick (2012) posits that NOS cannot be learned implicitly through engagement in doing science but "should rather be planned for instead of being anticipated as a side effect or secondary product" (Akindehin, 1988:73). We contend that a textbook that depicts a balanced perspective on the NOS can be employed as a resource that teachers can use in consciously addressing the goal of enhancing learners' conceptions of NOS.

We maintain that for there to be a radical shift towards a more balanced representation of the NOS in textbooks, publishers need to revisit the mandate given to textbook writers. In South Africa, new textbooks are first screened by a panel chosen by the Department of Basic Education before being approved for the list of books that schools can order from. In the review process, the panel evaluates the books against criteria drawn up by the department. To improve the chances of approval, publishers instruct writers to ensure that books adhere to these criteria. Given this scenario, it is likely that a change in the textbooks being produced can be effected should the department reflect in these selection criteria a more balanced perspective on the NOS.

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